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# THE EFFECT OF A POLYMERIC COATING ON THE CORROSION-FATIGUE OF A SUCTION ROLL ALLOY

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## ABSTRACT

A urethane coating is proposed as a method to extend corrosion-fatigue durability of a suction roll KCR 171 duplex stainless steel alloy in white water environment. Rotating fatigue specimens with and without coating were tested in air and in white water to produce SN curves. The results clearly show the improved durability of the coated samples especially in the high-cycle regime. The improvement is more pronounced at low (6 Hz) than at higher (20 Hz) frequencies because the coated samples are less affected than the uncoated ones by the corrosive environment. Other factors such as surface finish and white water temperature were found to have minor influence. The concept of a protective polymeric coating for suction rolls seems attractive but additional factors such as wear resistance, permeability and adhesion need further investigation.

## INTRODUCTION

Most of the large modern paper making machines use suction rolls made of stainless steel alloys. These alloys have greater strength and stiffness than the previously used bronze alloys. However, their corrosion-fatigue resistance was found to be inferior. The problem was well identified in the late 60's [1] and stimulated research to understand and solve the problem. As reported in a recent review [2], the research efforts included field performance surveys [3-5], alloys development [6-11] and laboratory research to develop a test with results correlating with service performance [2,12-16].

The metallurgy of the SS alloys progressed from the original martensitic and austenitic alloys to the more recent duplex austenitic-ferritic and ferritic-austenitic [6]. These duplex alloys like VK-A171/A271 [7], VK-A378 [8], 3RE60 [9,10] have better corrosion-fatigue properties due to their higher fatigue threshold and lower residual stresses level.

Other techniques have been proposed to fight the corrosion-fatigue problem including shot peening [2], inhibitors [2,4], anodic protection [17] and coatings [17,18]. The present paper investigates the use of a polymeric coating to improve the endurance of a duplex SS alloy suction roll under corrosion-fatigue conditions in a white water environment. The variables considered are the cyclic frequency and stress, surface finish and white water temperature.

## EXPERIMENTAL PROCEDURES

The material used in this investigation is a KCR 171 cast duplex stainless steel alloy. Its chemical composition and mechanical properties are given in Table 1. The fatigue specimens were machined from undrilled end sections of centrifugally cast shells. The microstructure of this material consists of austenitic islands within a ferrite matrix, with the austenite occupying about 55% of the volume.

Most of the tests were done in a white water of a chemical composition given in Table 2 at a controlled temperature of 50 ±2.5°C. The pH of the white water was adjusted to 4.5 and a circulating system insured that white water was continuously flowing on the specimen to maintain exposition to aerated white water. During the tests, evaporation was compensated by distilled water additions.

The fatigue tests were carried out at constant nominal stress in a cantilever type rotating bending machine. Conventional hourglass specimens of 6.35 mm diameter were used. The central portion of the specimens were enclosed in a plexiglass cell to confine the white water splashes. Two surface finishes were used on these hourglass specimens. The coarse finish consisted of a 240 grit emery paper mechanical polishing in the longitudinal direction. The samples with the fine finish were polished with finer papers followed by 6 or .25 μ diamond paste. The testing frequency was varied from 6 to 167 Hz.

Many of the samples were coated with a commercial polyurethane coating. The coating was applied by dipping and dried at 174°C for two hours. The cured coating was transparent and thin (≈ 0.1 mm).

## RESULTS

The results of the rotating fatigue tests are plotted on semi-log S-N curves on Figures 1 to 4. Figures 1 and 2 respectively show the results for the samples with a coarse and a fine surface finish. This method of presenting the data, highlights the effects of the coating and of the frequency. The same data are also shown on Figure 3 for the tests run at low frequency ($\leq$ 5 Hz) and on Figure 4 for the tests run at high frequency ($\geq$ 20 Hz). In this manner, the effect of the surface finish is better revealed.

### Effects of the coating

The main purpose of the investigation was to determine if a polymeric coating could effectively improve the corrosion-fatigue resistance of suction rolls. It is clear from all our figures that the coated specimens exhibit a superior endurance. It can be seen from Figure 1 that the improvement given by the coating is more important at low stresses and at low frequency which are the operating conditions of the suction rolls.

The fatigue limit of the uncoated specimens was not determined but is below 150 MPa. The endurance of the coated samples at $2.5 \times 10^6$ cycles is about 235 MPa which represents an improvement of more than 50%. The endurance

limit has not been determined at 6 Hz due to the prohibitively long testing time (20 days at $10^7$ cycles). The coated samples were tested at 20 Hz until 2 x $10^7$ cycles and no clear endurance limit was determined. However, the slope is less pronounced than for the coated samples. Data available in the literature [2,12] indicate that the endurance limit of suction roll alloys in white water is not reached before $10^9$-$10^{10}$ cycles suggesting that the difference between coated and uncoated samples might be even higher in the very high life range ($10^8$-$10^{10}$ cycles).

The dotted line on Figures 1, 2 and 4 joins the data obtained at very high frequency (100 and 167 Hz) in white water. At these high frequencies, the effect of the corrosion is greatly reduced and the dotted curve is considered to be representative of the intrinsic fatigue properties of the material. This is confirmed by two tests done in air (310 MPa, 6 μ, 100 Hz) shown on Figures 2 and 4, which lie on the same curve. It is interesting to see that most of the coated samples have an endurance much closer to this dotted line than to the data for the uncoated samples at intermediate (20 Hz) or low (6 Hz) frequencies. It indicates that the coating provides sufficient protection to almost completely eliminate the corrosive effect of the white water for most of the specimens.

Some of the coated specimens tested at 20 Hz failed in a much shorter time than the other coated samples. In fact, in some cases, their endurance was not better than the uncoated samples. This observation is not fully understood but could be related to a poorer performance of the coating on these samples. The presence of blister in the coating of some of the samples

was observed immediately after the tests. The symbols corresponding to these samples are marked by a dot on top of it on the figures. The blisters disappear completely after a few hours if the samples are left in air. It was also observed that the blisters were filled with liquid. The presence of these blisters is a sign of local adhesive failure of the coating and of white water sorption by the coating and diffusion throught it. The phenomenon of transport properties of polymeric coating has already been investigated [19].

The blisters were noticed on a limited number of samples (4) but it is probable that blisters were present on other samples since they were not systematically examined for it. The occurrence of these blisters indicates a non negligeable permeability of the coating. It is then tempting to explain the poor performance of some of the coated specimens by diffusion of white water through the coating even if blisters were not noticed on these specific samples. This explanation is however weakened by the fact that the four specimens on which the blister were observed did not show a reduced fatigue endurance. It is not either possible to explain why this problem of low endurance of some coated samples was observed only at 20 Hz. It can be mentioned that the centrifugal acceleration due to the rotation is in the order of 5 g at 20 hz and 0.5 g at 6 Hz and could contribute to the formation of the blisters at 20 Hz. Again, this hypothesis is not supported by the specimens on which blisters were noticed: two of them were tested at 20 Hz and two at 6 Hz.

Large casting defects (porosities) served as initiation site on some of the samples and could be responsible for the shorter life of certain samples.

However, as for the blister phenomenon, it was not possible to establish a systematic correlation between these defects and the coated samples failing prematurely.

Effect of the frequency

On Figures 1 and 2, it can be seen that the uncoated samples tested at 6 Hz have a lower corrosion-fatigue endurance than the samples tested at 20 Hz. This can be easily explained by the fact that the tests run at lower frequency last longer and increase the time of exposure to the aggressive environment. The reason why one sample tested at 4 Hz (345 MPa, 240 grit) had an unusually long life is not completely understood but could be attributed to scale factors since this sample had a smaller diameter (0.23") than the others (0.25").

The rotation frequency has little influence on the life of the coated samples. In order to make the latter statement, the scatter in the data and the coated samples showing premature failures (discussed in the previous section) have to be neglected. If not, Figure 2 might indicate that the coated samples have better endurance at 6 Hz than at 20 Hz which could hardly be explained.

Effect of the surface finish

The results on Figures 3 and 4 indicate that the influence of the surface finish is not important. In fact, the samples with the rough finish seem to

exhibit a slightly better endurance especially at 20 Hz. In the case of the coated samples this might be explained by a better adhesion of the coating on the rougher surface. In the case of the uncoated samples, the effect of the surface finish is not conclusive due to the small number of data points and the scatter in the results. Moreover, most of the uncoated, fine finish samples were found to fail due to casting defects which might have reduced their life. It is also believed that the outer layer of cold worked material due to machining and grinding has a beneficial effect on the fatigue life due to the presence of compressive residual stresses [16]; this layer is thinner on the fine polished specimens.

## Effect of the temperature

Some uncoated samples were tested at 80°C for a previous investigation [16]. These data points are indicated by a superimposed cross (+) on Figures 1 to 4. The results show that an increase in temperature from 50 to 80°C does not significantly reduce the endurance. In fact, in many cases the endurance is slightly better than for the corresponding samples tested at 50°C. There is no specific explanation for it and it is simply attributed to normal data scatter. The effect of the temperature on the coating was not investigated and all the coated samples were tested at 50°C.

## DISCUSSION

It is clear from the experimental data that a urethane coating improves the corrosion-fatigue resistance of rotating bending laboratory specimens.

However, it is not sufficient to extrapolate that covering the suction rolls with a polymeric coating would be an efficient way to improve their life. It is indeed encouraging that the best improvement was obtained at low stresses and low frequency and that the endurance stress was significantly increased in the high-cycle regime. On the other hand, all the service conditions were not realistically reproduced by the laboratory tests. Some of the factors to consider are the wear resistance, the viscosity, the permeability and the adhesion strength of the coating.

The wear resistance of the coating was not evaluated in the present study but would be a significant factor under service conditions. The causes of wear on a suction roll are the erosive action of the paper fibers in suspension in the white water circulating on all the surfaces of the roll and the seals of the suction box rubbing against the inside surface of the roll. A urethane coating was selected based on its excellent wear resistance but additional tests in long term service conditions are required.

A low viscosity coating would better penetrate the surface defects and porosities of the machined roll. It is usually admitted that the fatigue cracks initiate and propagate from these defects [2,13]. It has also been shown [13] that the fatigue stress intensity factor threshold, $\Delta K_{th}$, is lowered in simulated white water. Consequently, preventing the corrosive environment from reaching the bottom of the existing defects would be an effective way to increase the critical defect size and improve the corrosion-fatigue endurance. The coating used in the present investigation was diluted in an appropriate solvent to reduce its viscosity.

The observation of blisters on some of the samples revealed a problem of permeability and of adhesion of the coating. Water uptake by the coating might soften it and reduce its wear resistance. Lack of adhesion and formation of blisters might aggravate the problem and lead to tearing and peeling of the coating. Consequently, these factors need additional evaluation and the selection of the proper coating should be optimized for its wear, viscosity, permeability and adhesion properties after long term exposure to white water.

The coating is acting as a barrier against the corrosive action of the environment. What would be the corrosion behaviour in case of local failure of the coating? It is feared that accelerated attack could occur in the unprotected areas due to high corrosion current density. That effect should also be quantified to assess the feasability of the concept.

In spite of all these drawbacks, it is hoped that the concept of a polymeric coating might be a useful way to extend the life of suction roll.

## CONCLUSION

Rotating fatigue tests on coated and uncoated suction roll material produced the following conclusions.

1) The presence of a urethane coating significantly improves the corrosion-fatigue endurance in white water environment. The endurance of coated samples in white water is close to the endurance in air or at high

frequency which removes the effect of corrosion.

2) The improvement given by the coating is more important at low stresses and low frequency.

3) The presence of blisters on some of the coated samples suggests a possible problem of permeability and lack of adhesion of the coating which would require further research.

4) Premature failure of some of the coated samples was noticed. These failures might be attributed to an inconsistent performance of the coating due to the problems mentioned in the previous point.

5) Uncoated samples have a lower endurance at low frequency but the endurance of the coated samples is not significantly influenced by the frequency.

6) The surface finish does not have a significant influence on the endurance of the coated and uncoated samples.

The concept of a polymeric coating for the protection of suction rolls is promising but many problems still have to be investigated and solved. The selection of the coating has to be optimized and the following factors have to be considered: wear resistance, permeability, adhesion, long term degradation an possible attack in unprotected areas.

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## REFERENCES

1- Vadas R.M. and Thompson R., "The Suction Roll - Its Problems and Its Future, "Pulp Paper Can., 72, 1, 66-76 (Nov. 71).

2- Bowers D.F., "Corrosion Fatigue of Suction Roll Alloys - A Review", Corrosion 86, Houston, TX, Paper 144, NACE (March 86).

3- Wooster F.S., Moskal M.D. and McNamee J.P., "Stainless Steel Suction Roll Operating Life", A report by the Suction Roll Task Force of the corrosion Committee, TAPPI Press (1978).

4- Garner A., "Suction Roll Failures in Canada", Proceedings 70th Annual Meeting, CPPA, Montreal, Que. (Feb. 84).

5- Sailas V., "Critical Components of the Paper Machine Damage Caused by Metallic Corrosion", Pulp and Paper Ind. Corrosion Problems, Vol. 2, NACE, Houston TX (1977).

6- Gibbons J., "Failure-free Suction Roll Shells Made from Durable Stainless Steel", Pulp and Paper, 128-136 (April 77).

7- Murakami S. et al., "VK-A171/A271- New Cast Stainless Steels for Suction Roll Shells", TAPPI Eng. Conf., Houston, TX, Book 1, 5-18 (Oct. 76).

8- Hiraishi H. and Arii K., "Japanese Alloy Develoment", Engineering Conference, TAPPI Proceedings, Boston, MA, 611-613 (Sept. 84).

9- Vestola J., "European Alloy Development New Suction Roll Steels", Engineering Conference, TAPPI Proceedings, Boston, MA, 605-609 (Sept. 84).

10- Liljas M., Fridberg J. and Runefors K.C., "Avesta 3RE50 - A New Stainless Steel for Suction Rolls", Pulp and Paper Industry Corrosion Problems, NACE, Houston TX 88-93 (1974).

11- Moskal M.D., "Considerations in Suction Roll Materials, Fabrication and Service Environment", TAPPI, 57, 4, 115-118 (April 74).

12- Jaske C.E. and Catillo A.P., "Corrosion Fatigue of Cast Suction-Roll Alloys in Simulated Paper-Making Environment", Materials Performance, 37-43 (April 87).

13- Yeske R.A., "Prediction of Suction Performance in Paper Making", Materials Performance, 30-37 (Oct. 87).

14- Vadas R.M., "Corrosion Fatigue of Suction Press Rolls", Pulp and Paper Ind. Corrosion Problems, Int. Seminar, Chicago, Ill. NACE, Houston TX 81-87 (May 74).

15- Dahl C.B. and Rainger C.W., "Stainless Steel Suction Roll Performance Design and Materials", Pulp and Paper Ind. Corrosion Problems, Vol. 2, NACE, Houston TX (1977).

16- Ait Basidi M., Masounave J. and Dickson J.I., "The Corrosion Fatigue Behaviour in White Water of KCR 171", 1982 ASM Metals Congress, St-Louis, MO, Paper 8201-023, 23-280 and 82.

17- Congleton J. and Craig I.H., "Corrosion Fatigue", in Corrosion Processes, Parkins, R.N., ed., chapter 5, 209-269, Applied Science Publishers (1982).

18- Yannacopoulos S., Chaturvedi M.C. and Bassim M.N., "Use of Polymer Coatings to Prevent Corrosion-Fatigue", International Symposium on Fracture, 26th Annual Conference of Metallurgists, August 23-26, 1987, Proceedings to be published.

19- Mastronardi P., Carfagna C. and Nicolais L., "The Effect of the Transport Properties of Epoxy Based Coatings on Metallic Substrate Corrosion", J. of Mat. Sci., 18, 1977-1982 (1983).

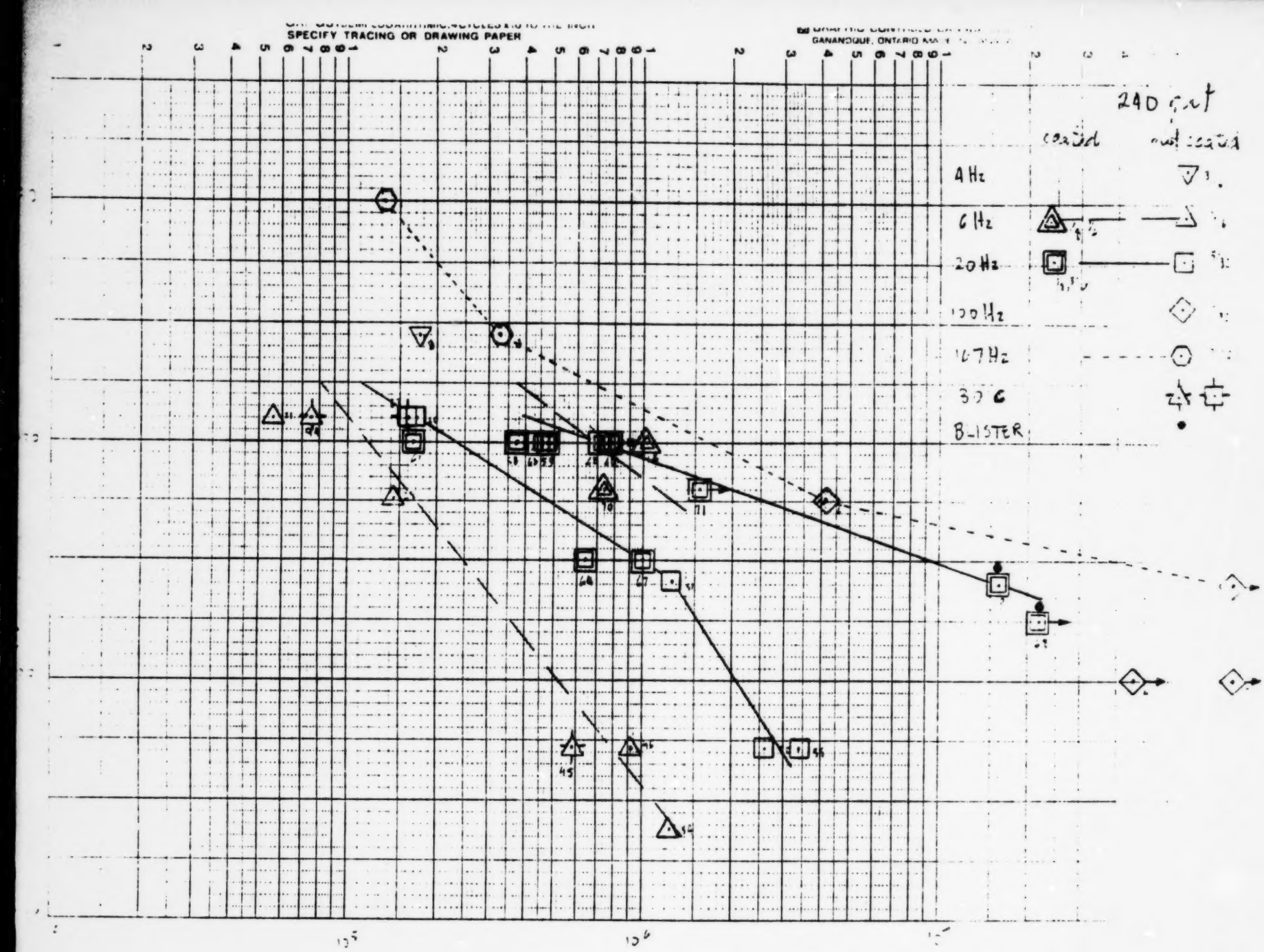
TABLE 1 Chemical Composition and Mechanical Properties of (KCR 171)

| Element | C | Si | Mn | P | S | Cr | Ni | Mo |
|---|---|---|---|---|---|---|---|---|
| wt% | 0.07 | 1.55 | 0.85 | 0.028 | 0.015 | 24.4 | 8.1 | 1.1 |

| Yield stress | Ultimate tensile stress | Elongation |
|---|---|---|
| 470 MPA | 700 MPa | 31% |

TABLE 2 Composition of Artificial White Water

| | | | |
|---|---|---|---|
| NaCl | (3.29 gm/ℓ) | 10 | mℓ |
| HCl | (0.01 N) | 3.16 | mℓ |
| $Na_2S_2O_3$ | (1.412 gm/ℓ) | 100 | mℓ |
| $Na_2SO_4$ | (1.479 gm/ℓ) | 100 | mℓ |
| $H_2O$ | (demineralized) | 1 | ℓ |


SPECIFY TRACING OR DRAWING PAPER
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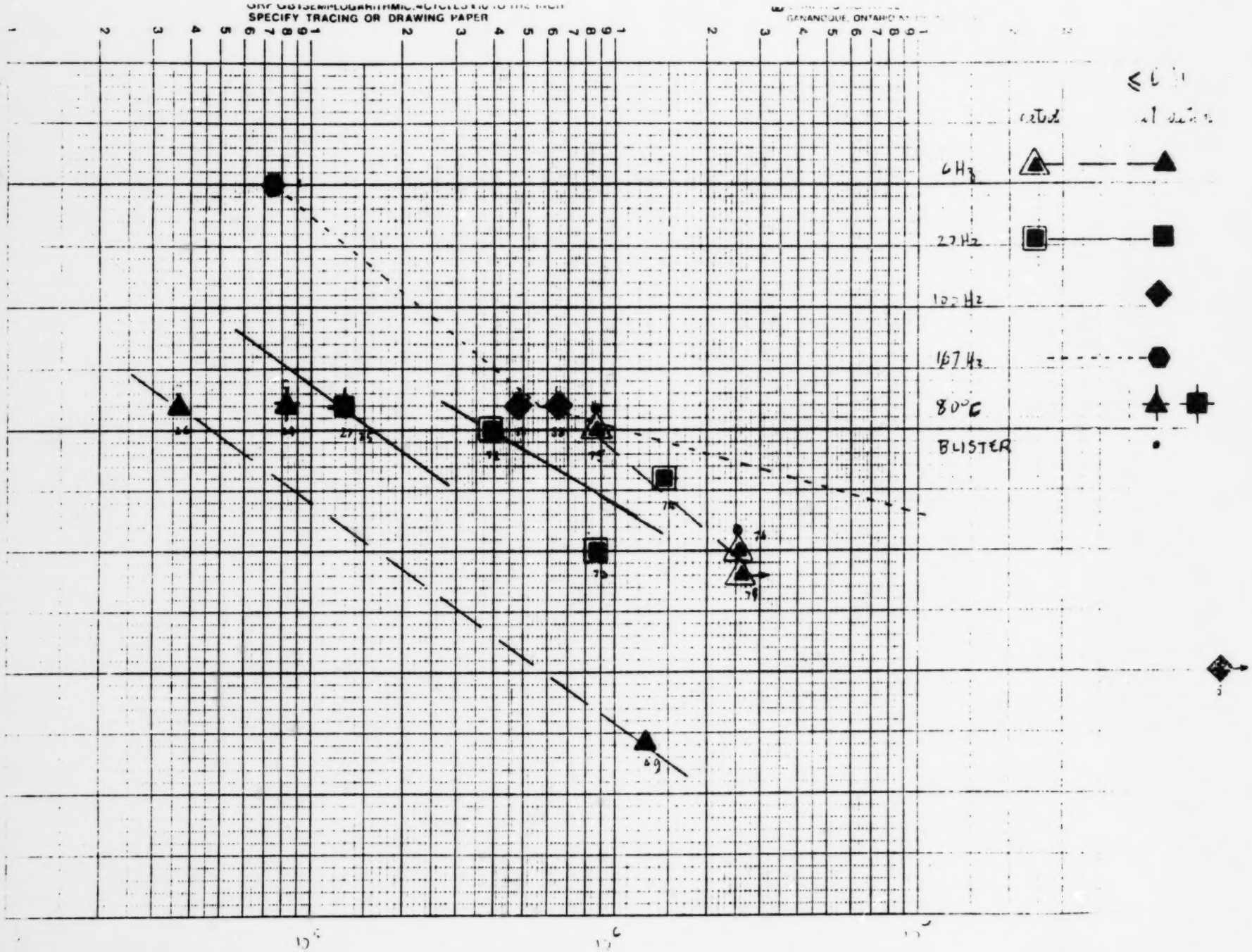
240 grit
4 Hz
6 Hz
20 Hz
120 Hz
167 Hz
30 G
BLISTER


SPECIFY TRACING OR DRAWING PAPER
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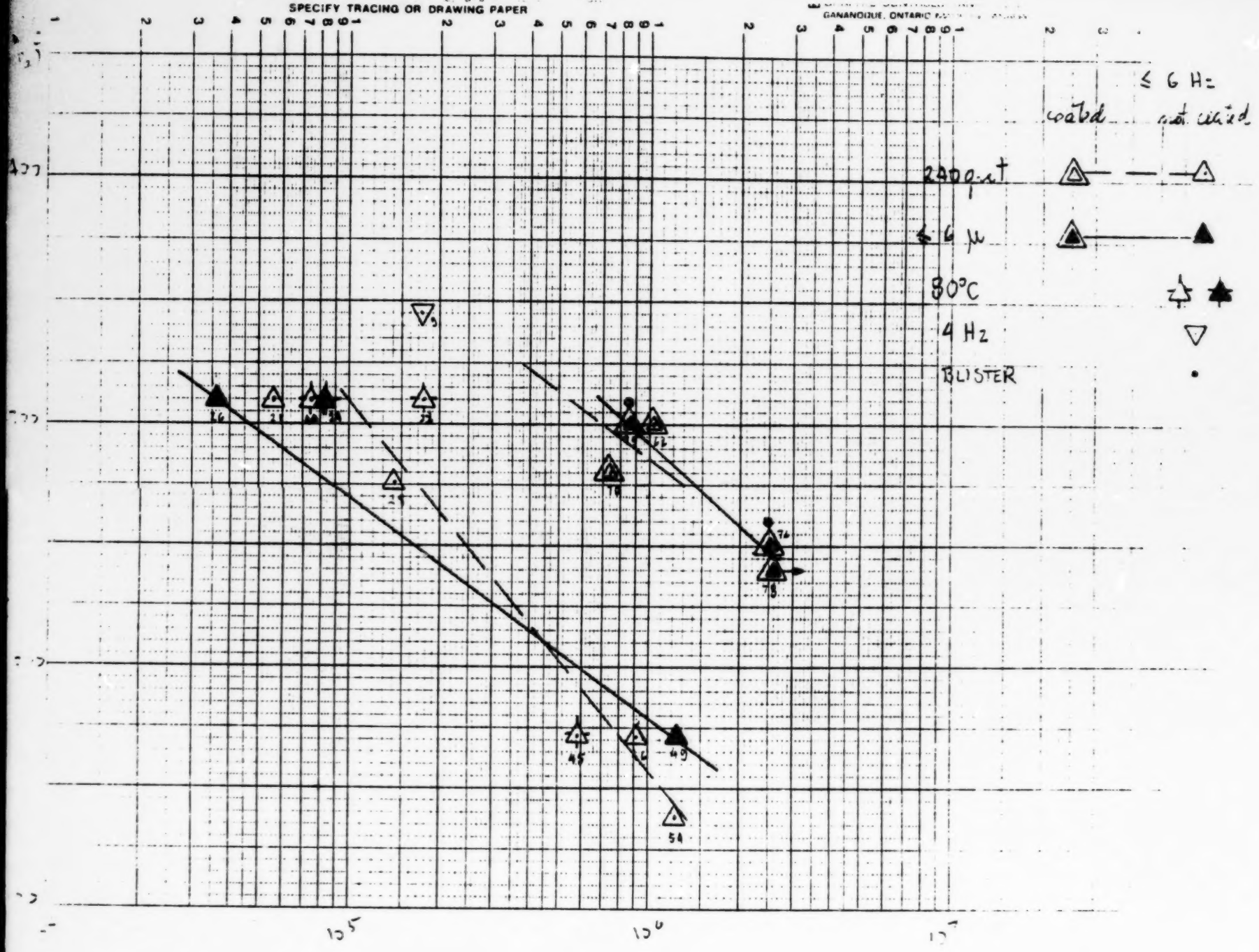
27 Hz
107 Hz
80°C
BLISTER


SPECIFY TRACING OR DRAWING PAPER
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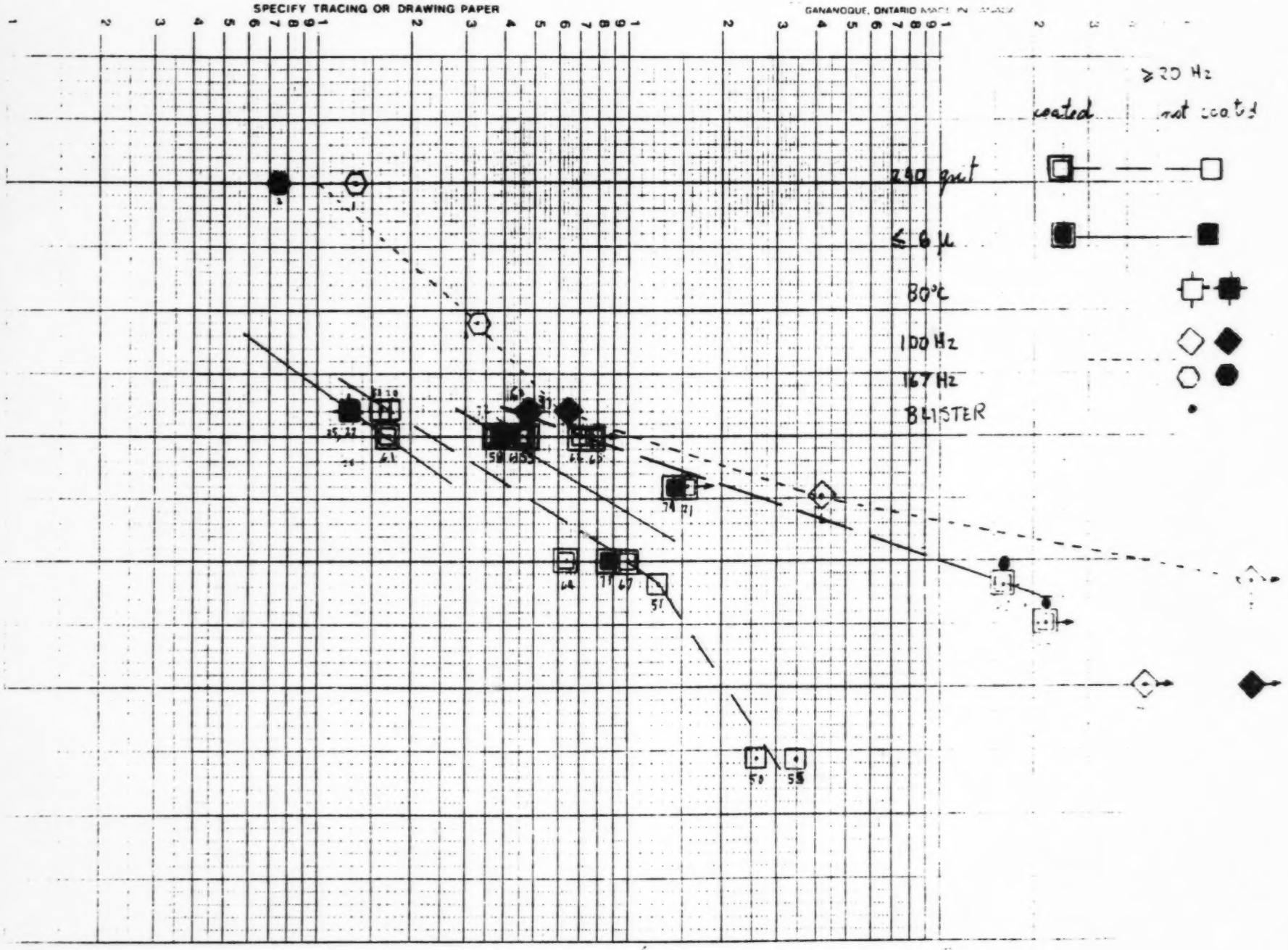
coated
not coated
240 psi
≤ 6 μ
80°C
4 H2
BLISTER
10^5
10^6
10^7


SPECIFY TRACING OR DRAWING PAPER
GANANOQUE, ONTARIO
≥ 20 Hz
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